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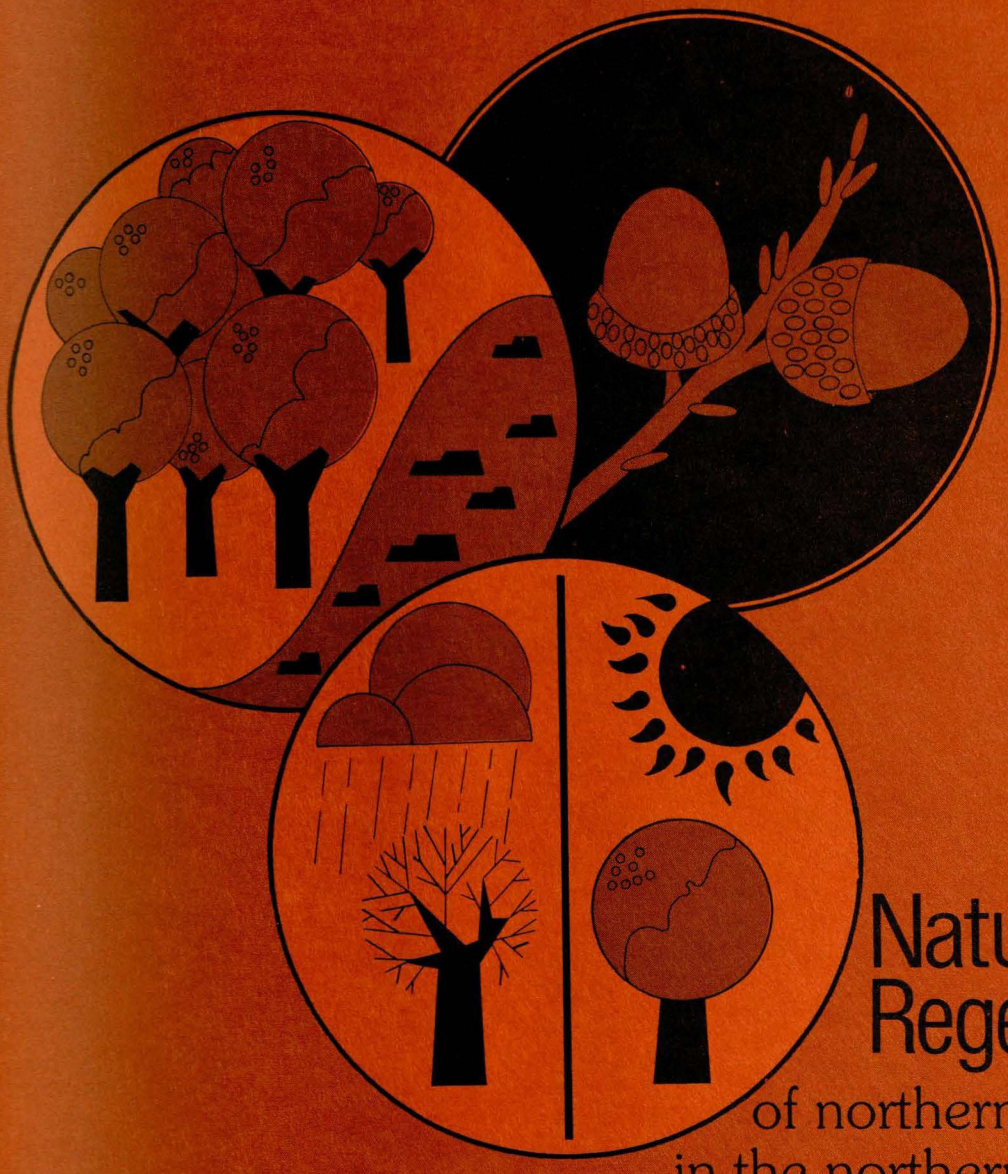

Natural Regeneration

of northern hardwoods in the northern great lakes region

by Carl H. Tubbs

NORTH CENTRAL FOREST EXPERIMENT STATION
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NATURAL REGENERATION OF NORTHERN HARDWOODS IN THE NORTHERN GREAT LAKES REGION

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The forest types collectively known as "northern hardwoods" (Quigley and Babcock 1969) occupy nearly 100 million acres in eastern North America. They extend roughly from Minnesota to the Atlantic coast and include parts of southern Canada. The area coincides approximately with Braun's (1950) hemlock-white pine-northern hardwood region and the Society of American Foresters (1954) northern region.

Prominent species are sugar maple, American beech, red maple, basswood, yellow birch, eastern hemlock, eastern white pine, the ashes, elms, and, in the northeast, red spruce. Northern white spruce, northern white-cedar, and black cherry are also common associates. American beech is confined to the eastern portion of the Great Lakes. As many as 17 cover types (Society of American Foresters 1954) may be considered "northern hardwoods". Ecologically, these types are related by successional trends that, under current climatic conditions, result in an abundance of sugar maple or beech.

The Great Lakes portion of the northern region has been repeatedly glaciated; geologically, the soils are young and the rolling topography contains a complex mixture of soils that are often influenced by ground water. The vegetation is also complex and many cover types are often found on a limited area.

The Great Lakes climate is characteristically humid (U.S. Department of Agriculture 1941) but the average precipitation varies from 25 inches in the west to 35 inches toward the east. Average mid-day July humidity ranges from 55 to 65 percent. Temperatures may drop as low as -50°F. during the winter and rise to 100°F. or more in the summer. Frost-free periods may be as short as 40 days in the northern interior but may extend over 170 days in southerly areas near the Great Lakes.

Establishing regeneration is an essential first step in forest management. Fortunately, most northern hardwood species can be regenerated without planting or artificial seeding. The purpose of this report is to review the information regarding the regeneration of northern hardwoods in the northern area of the Lake States. The first portion of the report focuses on the silvical characteristics of the major species, sugar maple and yellow birch, that affect regeneration, and the second describes the influence of silvicultural practices on regeneration.

The studies reported here were mostly done in the Upper Peninsula Experimental Forest in Michigan and the Argonne Experimental Forest in northeastern Wisconsin. These forests are in a region of heavy concentration of "northern hardwood" (fig. 1). Consequently, the results are applicable primarily to those northern forest areas and types whose successions will tend toward sugar maple, sugar maple-beech, sugar maple-basswood and to associations of hemlock-yellow birch and red maple.

Securing some sort of commercially important natural regeneration is usually a simple matter in most northern hardwood stands. On most sites the key to adequate regeneration is a supply of well established advanced seedlings and saplings. The tolerant maples are easily established after most partial cutting methods and respond well to subsequent release (Tubbs 1968). The chief problem is adequate representation of species either less tolerant or aggressive than the maples. Other concerns are stem quality and providing suitable browse for game animals or delaying tree regeneration where this is desirable for birds, animals, or esthetic reasons.

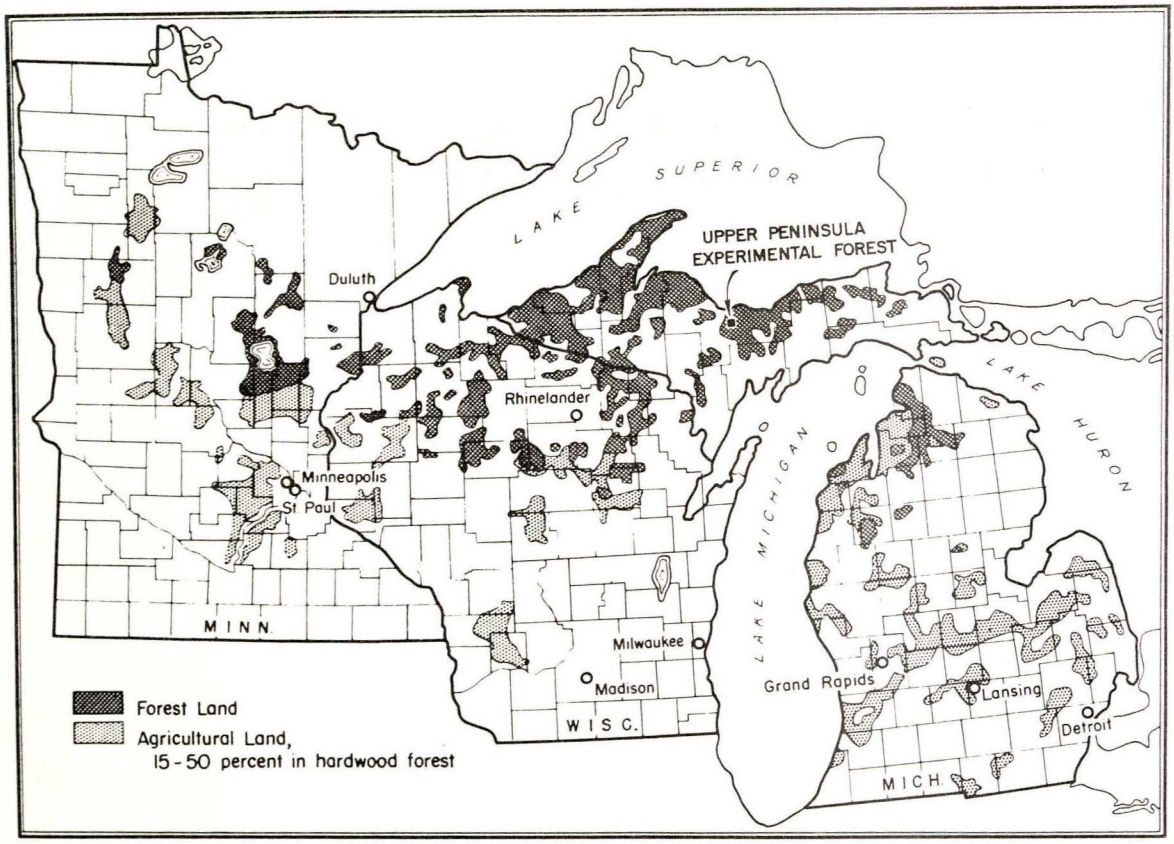

Figure 1. – *Concentrations of northern hardwoods in the Lake States.*

SILVICS

The Role of Sprouts

Except for basswood, sprout reproduction originating from stumps of old trees is usually undesirable for high quality timber production because of poor survival and form and propensity for extensive rot. Sprouts from seedlings and saplings are acceptable (Jacobs 1974). Clearcutting stimulates sprout growth (Eyre and Zillgitt 1953) as does heavy cutting in general (fig. 2). In old-growth stands, sprouting is greatest from stumps of young trees. Church (1960) observed that deer browsing reduced both sprout numbers and height growth. Fewer stumps sprout as overstories become denser. In second-growth[1], sprouting is not related to tree size or stand density but the percentage of stumps with sprouts declines with increasing time since cutting.

In addition to poor form, stump sprouts are subject to rots that enter directly from the decaying parent stump, or from the stubs of dead companion sprouts (Campbell 1938). Butt rot is more likely on sprouts that arise from large stumps and those originating high on the stump. Red maple is the species most susceptible to sprout butt rot followed by paper birch, basswood, sugar maple, black cherry, and white ash. Large stubs of dead companion sprouts with mature wood connections usually lead to butt rot of the surviving sprouts.

Consequently, sprout clumps should be thinned early, generally before age 20; sprouts with large stump wounds should be discriminated against, sprouts from small stumps should be favored, and old sprout clumps should be either entirely cut or entirely left alone.

Sprout growth makes desirable game browse. Thinning from below in young sugar maple pole stands can produce abundant sprouting (Church 1960) and may be a useful technique for foresters interested in browse production.

[1] *Second-growth is defined here as stands with less than 50 square feet of saw log-sized (9.6 inches d.b.h. minimum) trees and frequently overstocked with poles and/or saplings.*

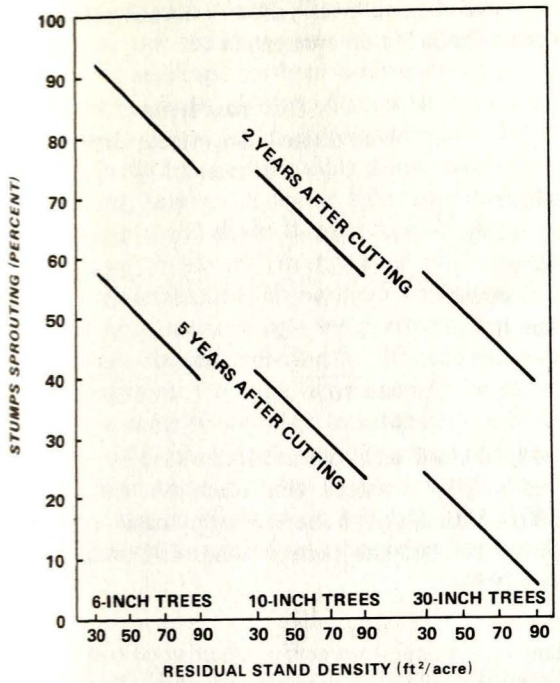

Figure 2. – *Effect of stand density, tree diameter (inches at breast height), and years since cutting on the percentage of old growth sugar maple stumps with living sprouts (Church 1960).*

The Role of Seedlings

Most hardwoods, balsam fir, and hemlock are prolific but irregular seeders. Poor crops or failures may occur often enough to significantly affect regeneration (Godman and Mattson 1976). When trees reach the large pole stage (8 to 10 inches d.b.h.) moderate crops are produced. Often several species bear good crops during the same year (table 1). In one study, 8 to 11 million seeds per acre fell in a year in a mature maple stand (Benzie 1959). As many as a million seedlings per acre may persist for the first year; few survive to the second year, but as many as 10,000 can survive to be more than 5 feet tall (Eyre and Zillgitt 1953).

The seeds of most commercially important species mature in the fall. White ash, black ash, sugar maple, beech, and red oak seeds are dispersed during leaf fall; eastern hemlock, yellow birch, and basswood seeds are dispersed throughout the winter months (U.S. Department of Agriculture 1974). Red maple and American elm seeds fall during late spring and early summer.

Table 1. – *Frequency of seed crops at the Argonne Experimental Forest (26-year average)*

(Years)

Species	Interval between good or better crops		Number of successive failures or good crops	
	Average	Range	Good or better	Poor or fail
HARDWOODS				
Black ash	3.6	1 to 8	2	7
Paper birch	2.7	1 to 8	2	5
Northern red oak	2.6	1 to 7	3	2
White ash	2.6	1 to 6	2	4
Yellow birch	2.7	1 to 8	2	3
Sugar maple	2.6	1 to 4	2	2
American elm	2.2	1 to 6	3	5
Red maple	2.1	1 to 6	4	5
Bigtooth aspen	1.5	1 to 3	6	2
Quaking aspen	1.4	1 to 3	6	2
CONIFERS				
Red pine	6.2	3 to 11	1	2
White pine	2.6	1 to 7	2	3
White spruce	2.5	1 to 5	2	3
Jack pine	2.4	1 to 6	7	2
Black spruce	1.9	1 to 4	5	1
Balsam fir	1.9	1 to 3	3	2
Hemlock	1.7	1 to 3	5	2
Northern white-cedar	1.6	1 to 3	6	2

Seed of most species is dispersed 300 to 400 feet by wind; in winter yellow birch seed may be blown long distances over the snow after thaws glaze the snow surface. Beech and oak seeds drop close to the tree.

Most species germinate readily after natural stratification. However, (except for maple) many newly germinated seedlings fail to penetrate the leaf mat and succumb because of low moisture and high temperature, which may exceed 150°F. on exposed leaf surfaces (Tubbs 1969a).

The timing of seed fall and length of time seed is exposed to dormancy-breaking conditions influence the number of seed germinating and surviving. In the Upper Peninsula, for example, sugar maple seed falls before and during leaf fall. The seed is buried between leaf layers where it is protected from temperature and moisture extremes. It germinates best at low temperatures (about 34°F.) and begins growth early in the spring when the leaf mat is wet and can be penetrated by young seedlings (Tubbs 1965). Yellow birch seed, on the other hand, drops after leaf fall and accumulates on top of the leaf mat. Optimum germination temperature for this species is higher than maple (about 50°F.) and germination normally begins later in the spring when the leaf mat surface begins to dry and becomes hard. By the time that temperature is favorable, the small birch seedlings are unable to penetrate the mat.

Birch germination depends on the length of time the seed is under dormancy-breaking conditions. Because yellow birch seed falls from September to June (Eyre and Zillgitt 1953), a year's seedfall receives various periods of dormancy-breaking conditions and optimum germination temperatures vary as a result. In one study, birch seeds sown outdoors after January germinated during the summer while those sown before January germinated in spring (Tubbs 1963). It is not uncommon to see the forest floor covered with newly germinated birch during wet periods anytime during the growing season. Seedlings resulting from late germination also cannot penetrate the leaf mat or are smothered by the October leaf fall. Consequently, scarification or burning to reduce leaf litter is necessary to produce the greatest number of birches and perhaps other small-seeded species as well.

Soil moisture is important in determining which species will dominate. Assuming other requirements are met, normally sugar maple will quickly become predominant after disturbances on well drained areas while on less well drained areas yellow birch and red maple will generally be better represented:

	Dominant stems	
	Well drained	Imperfectly drained
	— (Percent) —	
Hemlock	4	39
Sugar maple	58	10
Red maple	27	13
Yellow birch	3	10
Balsam fir	*	24
Other	8	4
	100	100

Poorly drained areas are usually invaded by mixtures of red maple, American elm, black ash, and various conifers. Ultimately, however, sugar maple tends to dominate all but the coarsest sands and swamplands (Braun 1950).

Many of the important northern hardwood tree species are shallowly rooted (red maple and white ash seedlings develop tap roots on deeper soils not influenced by ground water). The shallow-rooted tendency is accentuated on predominantly podsol soils, which characteristically have shallow A_1 horizons and pronounced A_2 horizons. In forest situations, most (90 percent or more) of the feeder roots of maple and birch are located in the top 3 or 4 inches of soil. Usually the leached A_2 horizon prevents any significant root development in underlying horizons. This restricts soil water supply to young seedlings. Forest disturbances or droughts that tend to dry out the upper soil layer may affect small seedling stands profoundly on soils that have shallow rooting zones because of a leached layer, high ground water, or bedrock.

The most abundant species in the northern hardwood types are at least moderately shade tolerant. Logan (1965, 1966a, 1966b, 1969, 1973) found that all species normally considered part of the northern hardwood group grew best in some shade except white pine, balsam fir, and white spruce; these species grow well in both partial shade and full sun (table 2).

"Tolerance" is a useful but potentially deceptive way for foresters to describe the general behavior of tree seedlings under various light conditions. Any one species' ability to grow under shade depends on site factors, such as moisture, temperature, and nutrients, as they are reflected by seedbed, soils, and amount and composition of overstory as well as the competitive

potential of other plants. The effect of these factors change as the seedlings develop. As seed or newly germinated seedlings, northern hardwoods are generally benefited by shade, which moderates temperatures and conserves moisture while allowing adequate light for growth. Partly because competing plants, such as grasses and shrubs, have much higher light saturation points than trees, partial shade also reduces the competitive potential of "intolerant" trees, grasses, or shrubs. However, once established, all northern hardwood species respond to increases in light by growing faster. At this point, some species, generally the shorter lived, require open conditions; the ashes and balsam fir for example, must have some release after establishment in order to survive, while others, such as the maples, hemlock, and yellow birch, may continue to grow slowly for long periods under heavy shade yet still retain the ability to grow rapidly after release from the competing overstory.

Table 2. – *Effect of shade on seedling height growth (from Logan)*

Species that grow well in deep shade[1] or half shade[2] but not in full sunlight:
Sugar maple
American beech
Species that grow well in one quarter shade[3] or half shade but not in full sunlight:
Sugar maple
American beech
Basswood
Yellow birch
White ash
Eastern hemlock
Species that grow best in half shade:
Paper birch
American elm
Silver maple
White-cedar
Species that grow well in half shade or full sunlight:
Eastern larch
Balsam fir
White pine
White spruce
Red pine
Species that grow best in full sunlight:
Jack pine
Black spruce

[1]13 percent full sunlight.
[2]45 percent full sunlight.
[3]25 percent full sunlight.

To further complicate matters, competition from other tree and lesser plant species influences a species' ability to survive under given "light" conditions in forest environments. Yellow birch competes poorly under even the most favorable forest conditions if sugar maple is present in large numbers, for example.

In addition, a species' "tolerance" may differ from one part of its range to another (Spurr and Barnes 1973) as a result of climatic and genetic differences.

Overstories can affect species composition in a number of ways. Shade cast by overstories affects micro-climate by reducing temperature and light and altering soil moisture. But, within broad limits, the density of the overstory has little influence on tree species composition of the seedling stand for a wide range of types in the northern hardwood group (Tubbs 1968, Tubbs and Metzger 1969). However, full sunlight as produced by disturbances such as clearcutting changes species composition to a mixture of shrubs, herbs, and trees when well established seedlings are not present (Metzger and Tubbs 1971) (fig. 3). Instead of favoring intolerant tree species, complete exposure commonly kills shallowly rooted, small, tree seedlings and allows intolerant grasses and shrubs to dominate, sometimes for several decades.

The composition of the overstory affects composition of the reproduction (fig. 4). Nine years after partial cutting old growth stands whose overstory was composed of hemlock, red maple, yellow birch, and sugar maple, seedling stands numbered from 12,000 to nearly 80,000 seedlings (6 inches tall to 0.5-inch d.b.h.) per acre. The composition of these seedling stands was more related to the original overstory composition than to the amount cut. Stands with overstories containing many sugar maple also had many sugar maple seedlings and few seedlings of other species. On the other hand, fewer sugar maple seedlings were found in stands whose overstories contained yellow birch and red maple. Numbers of yellow birch and red maple increased as the proportion of hemlock and red maple increased in the overstory. But numbers of yellow birch in the understory were not related to numbers of birch in the overstory.

Even though overstory density has little effect on tree composition, it does influence the rate of invasion by shrubs and grasses (fig. 5). Very dense overstories favor herbaceous plants, especially in younger stands. When overstories are composed mainly of poles and large saplings, the tree seedling stand is densely shaded, sparse, and severely repressed (Godman and Tubbs 1973).

Figure 3. – *A complete clearcut block with an average of 1,900 saplings per acre and a heavy cover of raspberries, grass, and scattered clumps of trees, 16 years after cutting. The bulk of the saplings were 1 in d.b.h. and occurred in a small area (Metzger and Tubbs 1971).*

Reproduction, density, germination, survival, and height growth are influenced by overstory density. Sugar maple and yellow birch germination and survival are favored by partial shade (Cunningham 1965, Ashby 1961, Metzger and Tubbs 1971) (figs. 6 and 7). Germination and survival of both species may be adequate on better drained soils under full sunlight, however (Tubbs 1969b and 1969c). Germination and survival of many of the other more tolerant species, although not studied intensively, would probably be similarly affected by overstory density. Height growth of young yellow birch seedlings on well drained scarified sites may be better under full sunlight than in partial shade (fig. 8).

As overstory density increases, seedling height growth rate generally declines. The 10-year average height growth of maple seedlings more than 4 feet in height was much greater under overstories originally cut to 50 square feet of basal area per acre (9.6 inches d.b.h.+) than 90 square feet. Both sugar maple and yellow birch are similarly affected (Burton *et al.* 1969) (fig. 9). Every opening in the overstory promotes good growth of a few seedlings, however, even when overstories are dense and average growth is low.

Suppression by the overstory for as long as 35 years does not prevent sugar maple from responding quickly to more growing space (Tubbs 1968). Observation indicates that other tolerant hardwood species and hemlock respond similarly but to a lesser degree.

Heavy cutting may make sites temporarily wetter (Godman 1959), which can retard tree seedling germination and growth on poorly drained sites. Shrub and grass

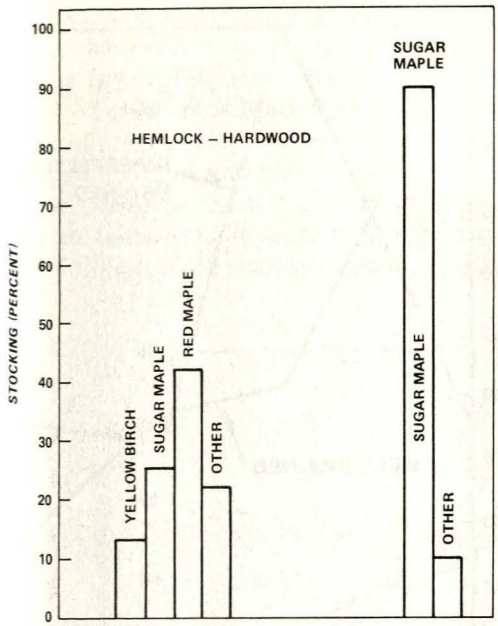

Figure 4. – *Species composition of the seedling stand 10 years after selection cutting in two forest types.*

invasions probably do not affect well established seedlings even after complete removal of overstories (Jacobs 1974) but may retard development of small seedlings and contribute to mortality after heavy overstory cutting (Metzger and Tubbs 1971). This is especially true of wet, shallow, or excessively well drained soils (Eyre and Zillgitt 1953).

Although there is an optimum combination of light, moisture and temperature for each species, a single species' performance in the forest depends on its ability to compete successfully with other trees and other plants. This may be only indirectly related to environmental factors. For example, in a controlled study of yellow birch regeneration requirements, only 6 of 64 different combinations of seedbed, light, and soil moisture did not support at least some birch seedlings after 2 years. In more than half the combinations, birch seedlings grew well (Tubbs 1969a). However, in field studies only a limited number of these combinations allowed birch to successfully compete with sugar maple (Tubbs and Metzger 1969) even though maple inherently grows slower than birch (Logan 1965) regardless of light conditions. Other studies (Tubbs 1973) showed that

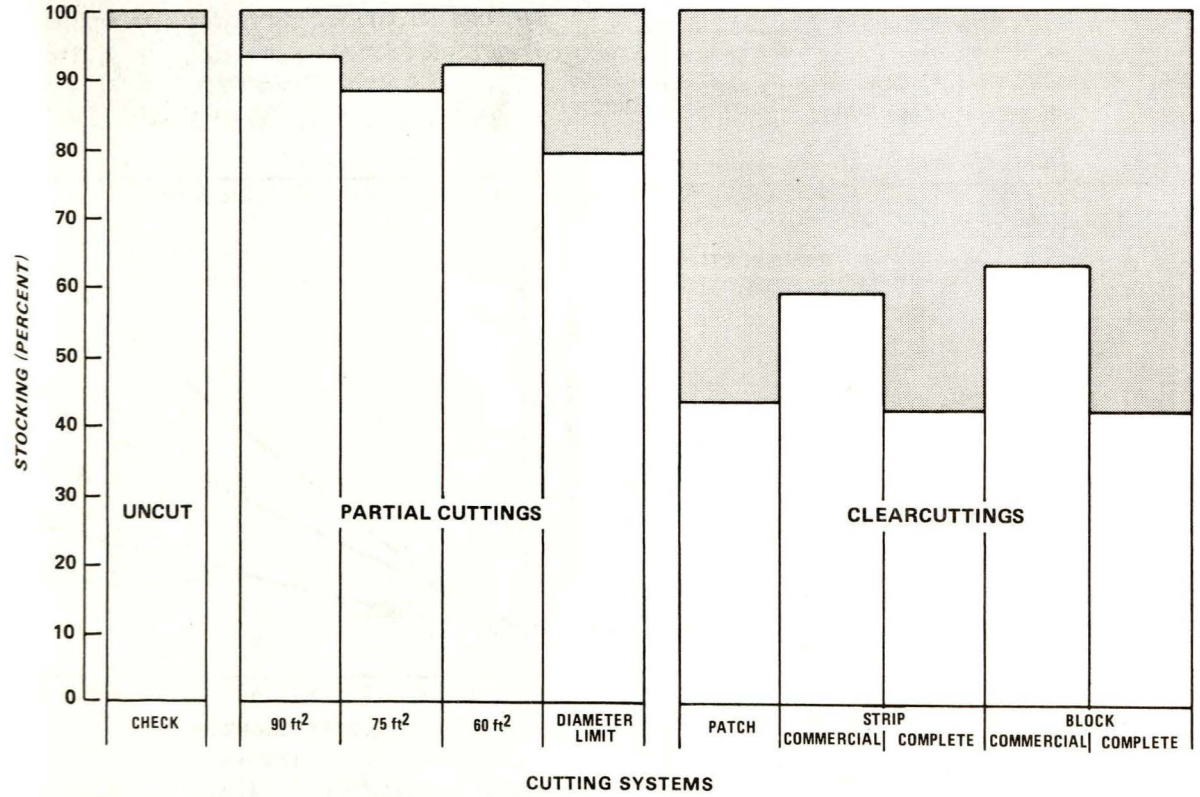

Figure 5. – *Average percentage of quadrats stocked with at least one tree of desirable species dominating 15 years after cutting. Gray area: Unstocked, or shrub or undesirable tree dominant.*

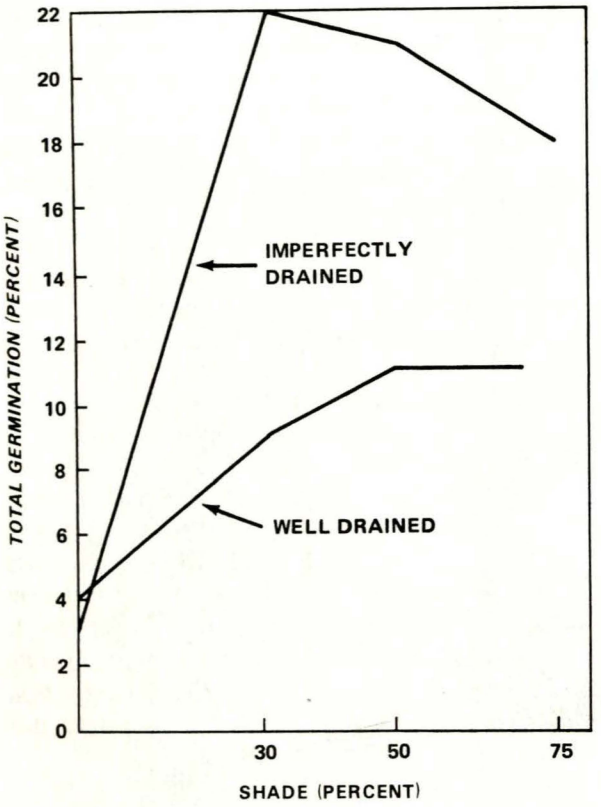

Figure 6. – *Germination of yellow birch by shade and drainage (Tubbs 1969).*

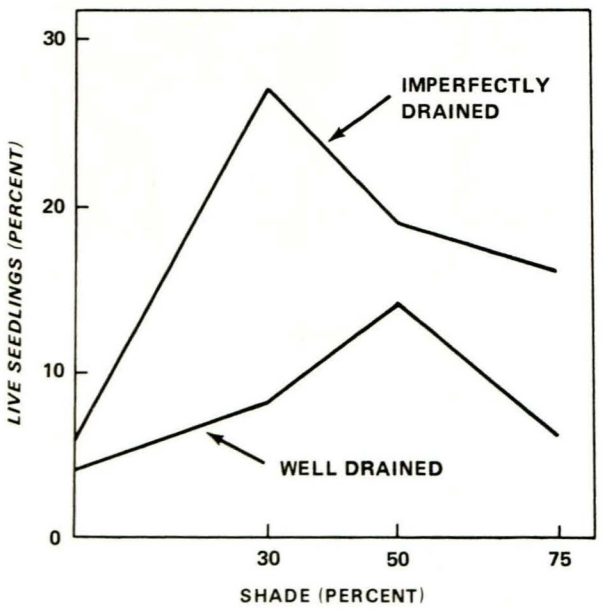

Figure 7. – *Live birch seedlings remaining after the second growing season by site and shade (Tubbs 1969).*

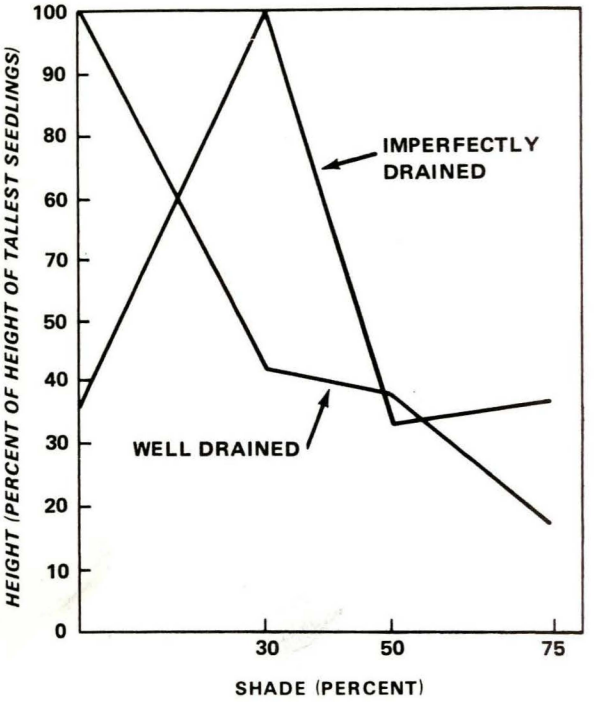

Figure 8. – *Percent of the height of tallest yellow birch seedlings on mineral soil seedbeds by moisture and shade (Tubbs 1969).*

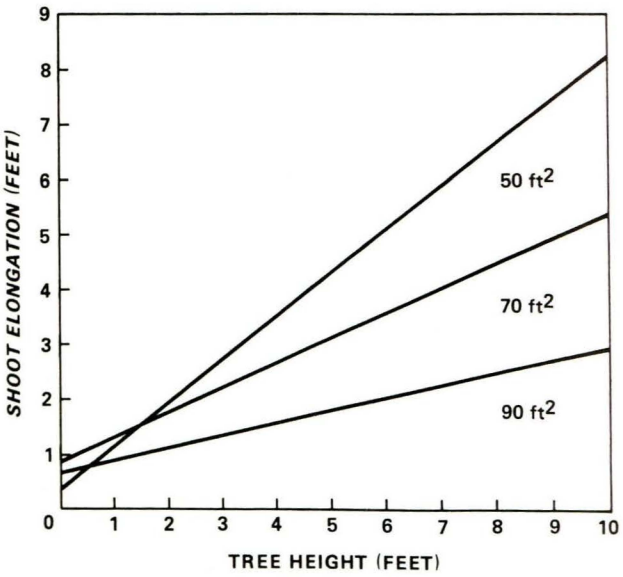

Figure 9. – *Maple shoot elongation in relation to tree height for three overstory densities (basal area) in the lowland hardwoods types (Metzger, unpublished M.S. thesis).*

maple exudes a growth inhibitor that prevents yellow birch establishment even though the environment is otherwise favorable. In forest situations, maple's ability to become established and survive under dense shade and grow rapidly when light conditions improve allows it to so dominate the reproduction stand that when more favorable conditions occur for other species they are unable to become established. In addition, rapid re-invasion of sugar maple into areas where it was removed causes a decline in birch numbers, apparently because of the inhibitor previously mentioned.

Field studies have shown that when sugar maple re-invades slowly and other environmental factors are suitable for birch growth, yellow birch stocking increases greatly (figs. 10 and 11).

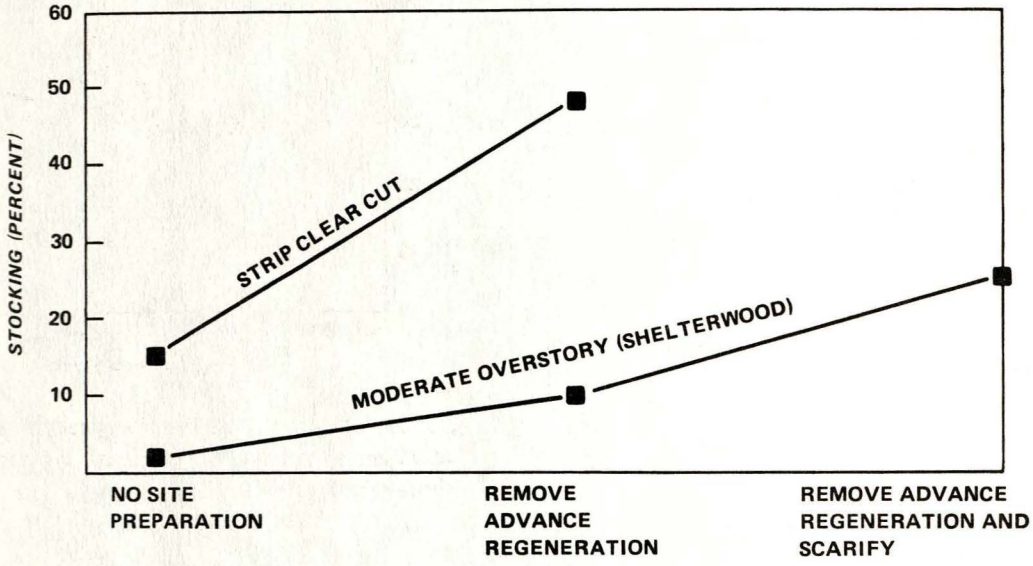

Figure 10. – *Influence of cutting method and site treatment on percent of sample quadrats dominated by yellow birch on moderate to well drained sites (Tubbs 1969).*

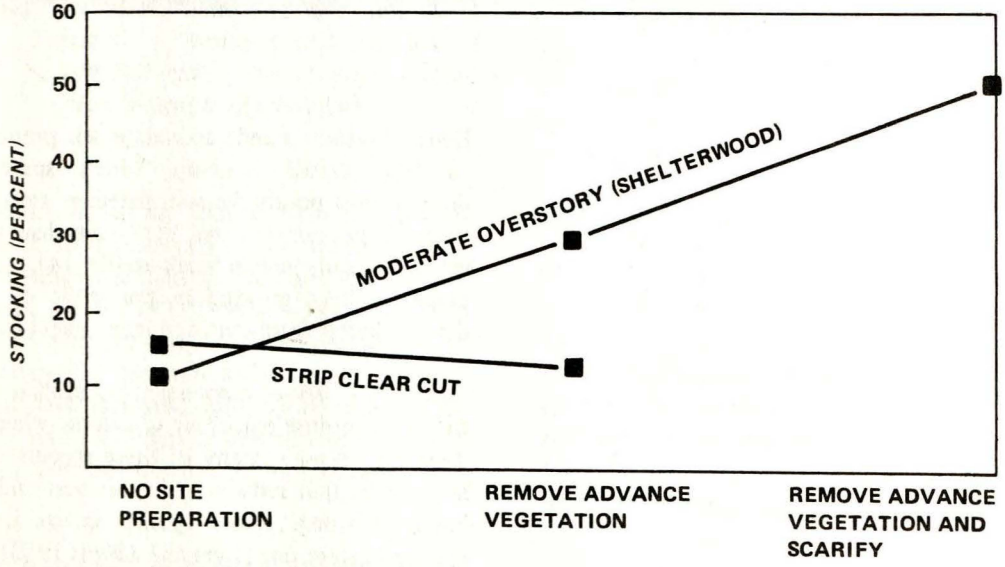

Figure 11. – *Influence of cutting method and site treatment on sample quadrats dominated by yellow birch on poorly drained sites (Tubbs 1969).*

Red maple sprouts commonly crowd out other tree species (Eyre and Zillgitt 1953). Beech competition is less often a problem in the Lake States than in the Northeast. Curtis and Rushmore (1958) suggest that heavy cutting may help favor maple over beech under certain circumstances. Arend and Scholz (1969) point out that red oak in northern hardwood stands competes poorly, as do other intolerant species. Basswood apparently competes favorably; it reproduces well from sprouts, which apparently are vigorous enough to compete with the ubiquitous sugar maple. Ironwood also competes well with sugar maple; in some cases it may even become a problem. It produces viable seed long before other northern hardwoods and may be prolific in openings made in young hardwoods.

Natural Form and Quality

Of the major species, red and sugar maple have the poorest natural form and quality. This is not noticeable during the seedling-sapling stage; even open-grown small maple saplings appear to have a strong central stem tendency, and defects such as forking quickly correct (fig. 12). However, maple crowns begin to break up between the small sapling and the small sawlog stages. Break-up is delayed in species such as white birch and basswood, which usually display good central stem tendencies. Even open-grown specimens of these latter species generally do not fork repeatedly as the maples do.

The quality of sugar maple seedlings is known to be partly genetically controlled. Kriebel and Gabriel (1969) found that seedlings of southern origin were more limby than those of northern origin. Excessive limbiness will ultimately result in short merchantable lengths, perhaps greater stem taper, and more limb-associated defects as trees mature.

Most northern hardwood species are alternately branched and do not have a true terminal bud; the maples, on the other hand, have opposite branching and a true terminal. It appears that damage to the apical portion of the stem has a longer lasting effect on the maples because the resultant forks are of approximately equal size (fig. 13); alternately branched species similarly damaged commonly have a clearly dominant fork member that would quickly return the tree to a single stem form.

The effect of these characteristics can be modified by the density and uniformity of the seedling sapling stand.

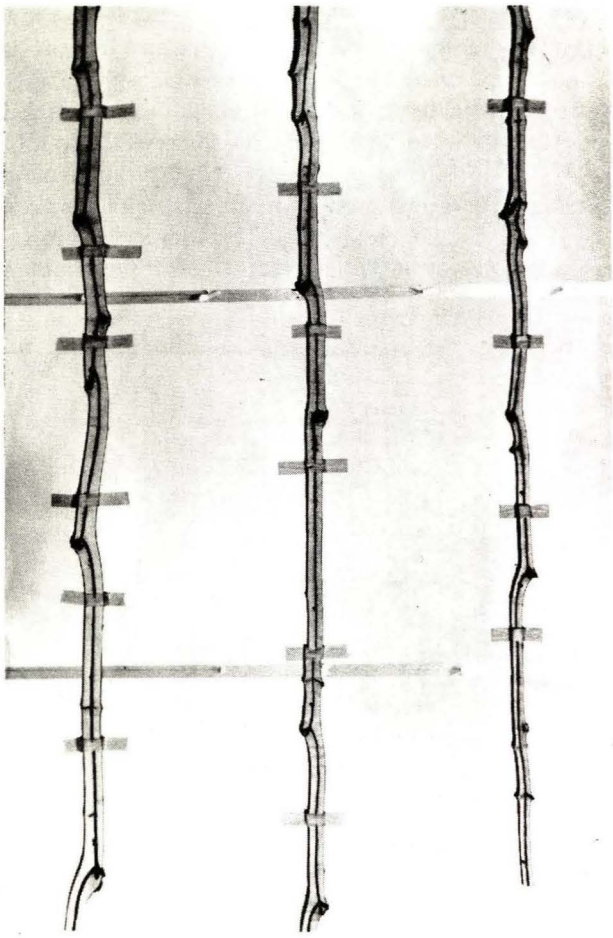

Figure 12. – *Longitudinal sections of the lower bole of sugar maple saplings show how radial growth corrects forking and associated crook and sweep (Jacobs 1969).*

Dense, uniform stands accelerate self pruning and tend to delay crown break-up. Widely spaced seedlings develop into poorly formed, defective trees with excessively large crowns and short merchantable lengths caused by early crown break-up (fig. 14). It appears that maple saplings growing in the shade of larger trees develop better form than dominant trees (Tubbs 1969b).

However, severe suppression of sapling sized maple results in profuse epicormic sprouting; when suppressed trees are released, many of these sprouts develop into large limbs that reduce quality at best and merchantability at worst. Other species appear less prone to epicormic sprouting (Eyre and Zillgitt 1953) but because they are less shade tolerant than the maples, severe suppression kills them.

Figure 13. – *Broken fork of pole-size sugar maple. Forks are caused by damage to the terminal bud by insects or physical factors such as wind or ice. Subsequent high winds or ice storms may break forks.*

Although dense side shade appears to be desirable in developing good stem form and clear boles, crown size and vigor are reduced in contrast to more open growth trees (Erdmann *et al.* 1975). Small crowns lead to increased epicormic sprouting both before and after release (Godman and Mattson 1970). Although it is often thought that increased light on epicormic buds produces sprouting, light plays at best a subordinate role to crown size and position in this regard (Books and Tubbs 1970).

Whether it is possible to develop, through cultural operations, crowns adequate to reduce epicormic sprouting under conditions unfavorable for forking and yet not reduce merchantable bole length is still a matter for research.

Sugar maple seedlings are often flattened by deep snow; subsequent growth does not entirely correct the stem curvature that results and maple saplings characteristically have what foresters call a "club foot" shape: the root collar area is noticeably swollen and from this the stem extends horizontally for a short distance to sharply curve to a vertical position (Fayle 1965). This phenomenon seems to have no effect on future merchantability.

Figure 14. – *The wide spacing of this plantation has caused low forks to persist, reducing merchantable length. Although the trees average 9 in d.b.h., the clear length is only 8 to 9 ft.*

Affect of Damage on Form and Survival

Browsing, especially by white-tailed deer, has been considered harmful to both form and numbers of seedlings. However, Jacobs (1969) showed that winter-browsed sugar maple seedlings grow about as well as unbrowsed seedlings and that ultimate tree form is not affected by severe browsing. Although forks are formed after the terminal bud is removed, one of the fork members quickly becomes dominant and the resultant crook is corrected by radial growth.

Damage by bud miners is prevalent in seedling sugar maple stands (Kulman 1967, Tigner 1966). Insects damage terminal buds causing the seedlings to fork. In the seedling-sapling stage, damage to form is not lasting but it can be serious to older trees.

Various birds feed on the winter buds of hardwoods; squirrels, mice, porcupine, and hare can kill or deform trees by winter feeding on bark.

Frost damage to northern hardwood seedlings has minor impact although such damage is common. Damaged seedlings usually grow as well as those undamaged (Tubbs 1969, Godman and Krefting 1960). Early fall frosts followed by late spring frosts can kill young yellow birch seedlings, especially those in full sunlight. Partial shade moderates low temperatures reducing damage, but heavy shade produces small seedlings that cannot survive even slight damage (Tubbs 1969).

Godman and Krefting (1960) observed that frost damage of yellow birch resembles that caused by deer browsing. Wind or snow break off frost-killed portions of twigs and stems, leaving a ragged tear like that of deer damage. Similarly, stem damage caused by Diaporthe resembles frost damage or can be mistaken for deer or frost damage after affected stem parts break off.

The ability to survive damage appears to be related to the "vigor" of the seedling. The amount of stem destroyed is less important than the vigor of the tree and the size and position on the buds left uppermost (Metzger 1977). Tree vigor is partly a reflection of growing condition: if seedlings are in good growing environment a high degree of damage can be tolerated. For example, in one study, most large yellow birch seedlings that grew slowly on water-logged soils died after severe damage but most fast-growing trees on well drained soils overcame the damage (Kamensky and Erdmann 1973). It is also known that repeated defoliation by insects can extend the normal hardening off process of trees, increasing their vulnerability to late summer frosts, especially when soil is dry (University of Wisconsin 1964). Presumably, defoliation by other agents could produce the same effect.

Breakage of seedlings and saplings during winter logging usually does not hinder regeneration. During removal of a shelterwood overstory of 80 square feet (4.6 inches d.b.h. and larger) from a sugar maple stand, nearly half the seedlings were damaged and a third destroyed (Jacobs 1974). However, mortality appeared to be confined mainly to seedlings less than 0.6 foot in height and stocking had only declined to 96 percent (45,000 seedlings per acre). Seedling sprouts that resulted from stem breakage grew rapidly and are considered desirable.

Winter cuts of a shelterwood over a yellow birch reproduction stand caused insignificant damage (Tubbs and Metzger 1969). However, summer logging in shelterwood stands may cause serious damage (Godman and Tubbs 1973). Apparently shallow-rooted seedlings are sensitive to summer logging.

Repeated partial cutting normally does not greatly reduce stocking of reproduction in selection stands (Tubbs 1968). Exceptions may occur in areas prone to sod and brush invasion. Where residual overstories are lightly stocked and advanced reproduction is not well established or absent, tree seedlings may not be able to become established in sodded areas for many years.

Serious wild fires are rare in the northern hardwood types. Spring ground fires can kill most reproduction-size trees (Burton *et al.* 1969), but reproduction damaged in fall ground fires resprouts the following spring. Repeated ground fires kill large saplings and poles, and hot slash fires kill sawlog-size trees. Wind and glaze are not especially damaging to small poles and saplings in managed all-age stands, but glaze may permanently bend small trees in even-aged stands or older forked trees. Sunscald appears to be most significant on young, sapling-size yellow birch and sugar maple, especially in even-age stands (Godman 1957). This type of damage seems to be sporadic, requiring conditions that do not occur often.

It is generally accepted that the density of seedling stands ultimately influences tree form. Studies are underway to determine quantitatively the relation between quality and density. In general, when exposed to light, branches of most tolerant northern hardwood species maintain themselves for long periods (Erdmann *et al.* 1975). The long term effects of sparse stocking are short boles and low forking (Godman 1969), (fig. 14). Probably at least 5,000 well spaced saplings per acre are needed to produce adequate quality (Jacobs 1974).

SILVICULTURE

Single Tree Selection

Single-tree selection for the northern hardwood type is defined in detail by Arbogast (1957). In general, the choice of trees begins with the largest and poorest and proceeds through the structure to the smallest. The cut is limited by the basal area chosen for each size class in the residual stand. Numerous studies (Tubbs 1969b) have illustrated the ease with which sugar maple regeneration is obtained with this practice (fig. 15). Within 5 to 10 years of the initial cutting, stocking with desirable species usually exceeds 70 percent and is commonly 90 percent or more regardless of overstory density (fig. 16). Overstory density affects growth of seedlings: cutting to leave only 30 feet of sawtimber (trees 10 inches d.b.h. and larger) produced dense sapling stands after 10 years while cutting to leave 90 square feet of sawtimber produced patches of saplings and many small seedlings.

However, dense second-growth pole stands seldom have many advanced seedlings because of the dense shade and/or scarcity of seed-bearing trees. In these

Figure 15. – *Sugar maple stand developing all-age structure after three cutting cycles, Upper Peninsula Experimental Forest.*

stands, improvement cutting or thinning normally does not immediately stimulate regeneration. Brush species cover even small openings quickly, but subside to be overcome by tolerant tree species in 10 years or so. In very young stands, sprouts may be dominant after cutting, along with various brush species (Church 1960, Ostrom 1938).

Group Selection

This technique has been used throughout the northern hardwood area in attempts to increase the production of moderately tolerant species. In the Upper Great Lakes this method is used primarily to promote yellow birch; consequently group size commonly ranges from 1/10 to 1/5 acre. One-tenth acre groups were shown to increase the proportion of yellow birch in old-growth stands in the Upper Peninsula. However, after 23 years many birch were overtopped by maple. Birch should have been released in the large seedling and sapling stage (Eyre and Zillgitt 1953). Yellow birch requires cool moist conditions to establish itself so the shady conditions of small group cutting tend to increase birch numbers especially if the area is scarified. Several moderately tolerant species have been promoted by some form of this technique in New Hampshire (Filip 1973) and Ontario (Burton *et al.* 1969). On the other hand, group selection in second-growth stands led to long-lived grass-brush invasions in Wisconsin (Metzger and Tubbs 1971).

The management of groups is unwieldy for large forest areas partly because of the groups' small size (1/10 to 1/5 acre) and because a large number of groups must be accounted for to schedule cleanings, thinnings, and reproduction cuts. When early cultural practices are not

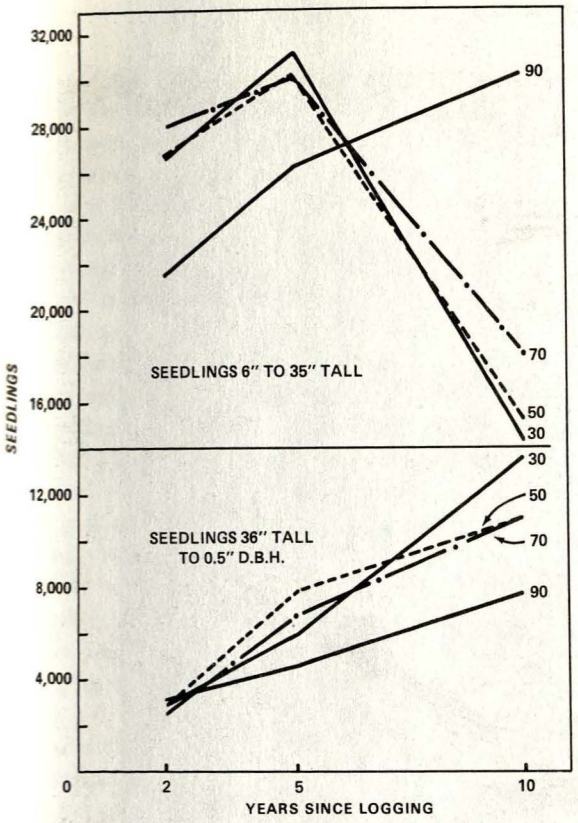

Figure 16. – *Abundance of sugar maple seedlings under different levels of residual overstory (30, 50, 70, and 90 ft² of basal area) (Tubbs 1969b).*

necessary, or on small tracts, group selection may be practical under present economic conditions (Roach and Gingrich 1968). It is an accepted practice in conjunction with individual tree selection: groups are not planned but are created when markers find a group of mature trees. If no attempts at scarification are made the resulting regeneration after cut is primarily of tolerant species; if scarification is done other species may invade.

Group selection has evolved to narrow-strip clearcutting (Marquis 1966) in the Northeast where it seems to accomplish about the same purpose in a more manageable way. However, uniformly successful application of strip clearcutting to promote either moderately tolerant or intolerant species has not been demonstrated in the northern Lake States. Here, cutting to promote less tolerant species has evolved from group selection to shelterwood.

Shelterwood

Shelterwood cutting is defined in detail by Godman and Tubbs (1973). In general, it requires a preliminary cut 10 years or so before final removal to establish advance reproduction from seed or seedlings. It is necessary to start this preliminary cut from below, removing the smallest trees first, then advancing to larger trees. The objective is to leave an overstory canopy which covers roughly one-half or more of the area (fig. 17). The final removal releases the advance regeneration.

Shelterwood cutting can produce fully stocked even-age stands of both tolerant and moderately tolerant tree species (Tubbs and Metzger 1969, Godman and Tubbs 1973). Shelterwood has been used to regenerate species that require shade or respond poorly to full sunlight during the germination-establishment period. Many northern hardwood species fall into this category. For example, both sugar maple and yellow birch may reproduce easily after strip clearcuts on well drained soils but even advanced growth may perish after complete overstory removal on other soils (Tubbs 1969b).

Two-cut shelterwoods experimentally done in Upper Michigan and northern Wisconsin (Godman and Tubbs 1973) illustrate several principles that must be followed to successfully regenerate dense, even-age stands.

The first cut must be from below. The dense shade cast by saplings and poles represses regeneration unevenly. Where groups of small trees are numerous, a patchy stand of various size seedlings and saplings may result (table 3). If not removed before overstory removal, the taller reproduction becomes excessively branchy.

Because basal area does not adequately describe crown size of forest-grown hardwood trees, regulation of overstory is best done by judging the amount of crown area to be left (Godman and Tubbs 1973). Where advanced regeneration is small and sparse, the crown area to be left should be relatively great to prevent invasion by brush and grass species. Where advanced regeneration is well distributed and large, up to 50 percent of the crown area may be left.

The timing of removal cuts is based on the vigor and density of the reproduction. Generally it should be safe to remove the overstory when the reproduction is 2 to 4 feet tall. Seedlings smaller than this may die on many sites after overstory removal. Overstories have been removed when reproduction is up to 10 feet tall without significant damage (Jacobs 1974).

Figure 17. – *Shelterwood stand 3 years after the initial cut.*

Table 3. – *Influence of different amounts of crown cover on stocking and height growth 7 years after a shelterwood cutting*

Stand number	Crown cover		Seedlings per acre	
	Initial cut	After 7 years	Total	More than 3.6 feet tall
	Percent		*Number*	
1	60	76	44,040	9,800
2	76	94	33,400	2,500
3	130	158	17,100	700

When it is desirable to increase the proportion of less tolerant or aggressive species, use of the shelterwood system with site preparation has been most successful on sites not conducive to rapid invasion of competing tolerant hardwoods (Tubbs and Metzger 1969). These sites generally have moderately and less well drained soils supporting red maple, American elm, hemlock and other conifers. Advance reproduction should be destroyed and the area scarified to provide optimum conditions. If scarification is not possible, poisoning of advanced regeneration will also increase the proportion of less tolerant species although not to the extent that scarification will (fig. 10). Eastern hemlock regeneration success is stimulated by artificial seeding after scarification.

Sprout growth may cause difficulties in prospective shelterwood stands that were previously partially cut and have developed some structure. For example, a recent preparatory cutting at the Upper Peninsula Experimental Forest has resulted in vigorous and widespread sprouting, which stemmed from stumps of the numerous poles and large saplings produced by partial cutting in the past.

Clearcutting

Clearcutting as used here refers to a regeneration cut that removes all trees from an area with the intent of starting a new even-age stand of natural regeneration by seed. It is important to distinguish and emphasize the difference between this and the final removal cut of a shelterwood system, which is intended to release advanced regeneration. The latter is also a clearcut. In the first case, clearcutting is a regeneration cut but in the case of shelterwood, clearcutting is simply a cutting used after a rotation for final release of reproduction. These clearcuttings are done for different reasons and are preceded by a different set of circumstances. Because confusion exists about the meaning of the term clearcutting, it appears to be wise to use the words final removal where the purpose of the clearcut is to release advanced regeneration and to use clearcut with the applicable modifier (i.e., commercial, with artificial regeneration, etc.) where clearcutting is done for some other purpose.

Accidental shelterwoods were often created in the past by clearcutting mature hardwood stands in which mortality or commercial selection for species or grades had previously opened up the overstory. When this happened advanced regeneration became well established and "clearcutting" produced a well stocked, even-age stand. In essence, the clearcutting was a final removal. Similarly, even-age stands of the future are not likely to require preparatory or seedling cuts near the end of the rotation because any regularly thinned northern hardwood stand will regenerate after mid-age. The final clearcut in this instance is also a final removal because its silvicultural purpose is to release advance regeneration.

Clearcutting trials date from 1926 in the Lake States. It appears that successful "clearcuts" were often due to the presence of well established advanced reproduction before cutting (Tubbs 1969b). A recently completed comparison of strip, block, and patch clearcuts of stands without large advance regeneration shows that stocking was variable, shrub and grass invasion common, and few intolerant or moderately tolerant species were produced regardless of the shape or orientation of the cutting area (Metzger and Tubbs 1971).

Because establishment of tolerant species is especially benefited by shade, strip clearcutting might be thought to be better than block clearcutting. However, in this study there were no differences in stocking between strips and blocks. A strip clearcutting in old-growth hemlock-hardwoods on a shallow silt loam at the Argonne Experimental Forest is still poorly stocked after 10 years. Another strip clearcutting study (1- and 2-chain-wide strips positioned N-S and E-W) at the Upper Peninsula Experimental Forest indicates that where all vegetation was removed, regeneration after a good seed year was plentiful on the better drained portion of the study. Yellow birch was prominent in the new stand. However, in the poorer drained portion of the study area, after a less bountiful seed year, reproduction was poor 5 years after cut and is composed primarily of sugar maple after 10 years. Where advance regeneration was not poisoned, the seedling stand after the removal cut was uniformly dense and composed primarily of sugar maple.

In essence then, soil type, soil moisture, and seed year are major influences on species composition after clearcuts. Following clearcutting, natural tree regeneration is likely to be irregular in size and distribution, most tree species will be tolerant, and areas may be invaded by undesirable species or dominated by sprout growth in some cases.

Apparently, complete overstory removal without well established regeneration may delay regeneration, especially on extremely wet or dry soils. On such soils overstory moderates temperature-moisture extremes, which is normally necessary for regeneration of northern hardwood tree species.

SUMMARY

Fully stocked stands of species such as the maples or beech are easily obtained by partial cutting. Repeated partial cutting under an individual tree selection system results in regeneration stands of many size classes while partial cutting done as part of a shelterwood system results in even-age regeneration stands.

Regeneration after partial cutting on wet soils will commonly be composed of a greater range of species than on the better drained soils, especially if sugar maple is not the dominant overstory species. On the better drained soils regeneration is predominantly sugar maple.

The occurrence of a northern hardwood species depends initially on seed production during favorable years. Seed production is usually adequate although sporadic enough to cause regeneration failures on clearcuts. Site factors, especially soil moisture, play an important role in determining the proportions of species that will germinate and survive. Competition between grasses, shrubs, and tree species affects both the density and composition of tree regeneration.

Partial shade generally benefits all northern hardwoods during establishment. In many situations northern hardwoods require partial shade for successful establishment but in a few can reproduce from seed without the benefit of shade. Partial shade also reduces the intensity of sprouting.

Once established, all are benefited by an open overstory. In forestry practice, the amount of opening is constrained by quality considerations: in all-age stands an overstory sufficient to encourage natural pruning must be maintained for the few hundred saplings normally present. In even-age stands, several thousands of reproduction-size stems are necessary to ensure natural pruning.

Light-seeded species are benefited by seedbeds that do not retard germination by quickly drying out or presenting physical resistance. The less tolerant or less aggressive species such as yellow birch and eastern hemlock can be regenerated by scarification and/or removing advanced regeneration in partial shade.

Clearcutting success has been variable. The most successful clearcuts have been on soils of moderate texture and drainage following good seed years. Clearcutting does not always produce desirable stocking of intolerant or moderately tolerant species. Consequently, the natural regeneration of moderately tolerant or tolerant species should be stimulated by partial cutting in selection or shelterwood systems.

These results may seem at variance with those obtained in other areas of the northern hardwood region. Both in southeast Canada and the northeast United States some form of clearcutting successfully produces desirable moderately tolerant and intolerant species (Burton *et al.* 1969, Trimble 1973, Filip 1973). However, both the climate and composition of the eastern northern hardwoods vary markedly from the northern Lake States. For example, American beech and red spruce are notably lacking in northern portions of Lake States forests and are prominent farther east. In the east, rainfall may be more than double that of average Lake States conditions and evapo-transpiration rates are generally less than in the Lake States. Consequently, it does not seem surprising that clearcutting by patch or strip should be more successful in those areas than in the northern Lake States where a partial overstory must protect young seedlings from excessive temperature and moisture loss in most instances. In those portions of the northern hardwood range where such species as black cherry, yellow poplar, and the oaks are mixed with northern hardwood species, patch clearcutting is an accepted practice.

RESEARCH NEEDS

Regeneration requirements of only a few species are well known. The birches have been intensively studied but other important species such as red maple, basswood, and the ashes have been largely ignored. The advent of strong multiple-use demands makes it necessary to understand the requirements of many tree species (such as eastern hemlock and red maple) that are important for both timber and recreational use. More significance is now attached to vegetation other than trees and to associated animal life not only because of their recreational value but because of their role in protecting the site. The behavior of species in natural communities has also only been occasionally studied by systematic methods so that the reasons for significant changes are difficult to judge. The discovery that tree species in the northern hardwood type may exude ecologically significant toxins or inhibitors deserves more study because these substances may play an important role in determining species occurrence and regeneration success.

In general, regeneration study has been limited to specific geographical areas so that important regional differences are difficult to discern and understand. It seems important to be able to distinguish these differences so that forestry practice will not be misapplied to similar appearing but ecologically different cover types.

The use of heavy machinery provides more economical and less wasteful methods of harvesting, so new regeneration methods are likely to be needed as new harvesting equipment becomes available. As more is learned of the genetics of hardwood species the necessity of finding ways to introduce better strains into natural forest areas will also be needed. Better genetic information may also aid in refining present practice in natural stands.

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1977. Natural regeneration of northern hardwoods in the northern Great Lakes Region. USDA For. Serv. Res. Pap. NC-150, 20 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Reviews silvical and silvicultural information about natural regeneration pertinent to forestry practices in Lake States northern hardwood types. Seed production; effects of light, moisture, temperature and competition on establishment and growth; and how damage affects mortality rates and form are covered. Clearcutting, selection, and shelterwood experiments are discussed.

OXFORD: 231:(77). KEY WORDS: northern hardwood, *Acer saccharum*, *Betula alleghaniensis*, natural regeneration, silviculture.

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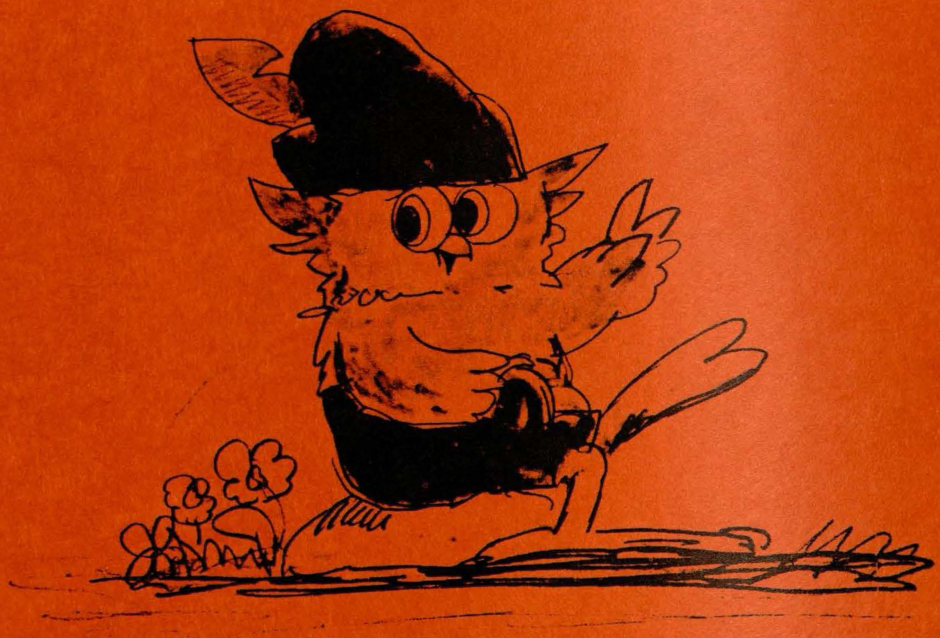

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